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Electric Resistivity of Soils and Upper Permafrost Layer of the Gydan Peninsula

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Abstract: Soils of the Gydan Peninsula have been investigated during the complex expedition "Yamal Arctica 2013" during the "Professor Molchanov" vessel route in August and September 2013 with special aim to characterize soil morphology in relation with parameters of electric resistivity with use of vertical electric sounding methodology. Data obtained show that soils investigated are quite different in terms of solum morphology, soil stratigraphy and active layer thickness. Main soil types of the Gydan Peninsula (Siberia, Russian Federation) are Cryosols with features of raw organic matter accumulation and gleyification features. These soils dominate on the watersheds and in lowlands due to poor drainage of parent materials and presence of continual permafrost in landscape. In some cases, two Gleyic layers formed in one soil profile – one in the upper or middle part due to seasonal fine earth over moisting, and second one – on the contact of the solum with permafrost. Histic soils with Cryic features are more typical for lowlands (relief depressions). Soils of the Beliy Island are presented by slightly podsolised soils in upper part, this is due to lithological contrast of sediments (sandy textured solum changes by loamy textured one). The Electric resistivity (ER) was measured directly in the soil profiles with using the vertical electrical sounding (VERS) method, which provides data on the changes in the electrical resistivity throughout the profile from the soil surface without digging pits or drilling. This method allows to divide the soil pit vertically into layers with different properties. A VERS modification with shorter electrode spans was used to study the upper up to 5-m thick layer in detail. The distance between the A and B electrodes was from 5 to 500 cm. Soils have been sounded be thoroughly from the 5 cm to 3-5 m in depth. It was shown that use of VERS methodology in soil survey is quite useful for identification of the permafrost depth without digging of soil pit. This method allows identify soil heterogeneity, because the ER values are strongly affected by soil properties and intensively changes on the border of different geochemical regimes, i.e. on the border of active layer and permafrost. VERS data obtained show that the upper border of the permafrost layer coincides with that border, which were identified in field on the base of soil profile morphology. The VERS method also can be used for identifycation of Gleyic, Histic and Podzolic layers. VERS methodology is useful for preliminary soil survey in the regions with permafrost affected soil cover. It is also can be applied for differentiation of soil-permafrost layer stratification in field soil pits.

Zusammenfassung: Im Zuge der interdisziplinären Expedition „Jamal-Arktis" mit dem Forschungsschiff „Professor Moltschanow" im Sommer 2013 wurden die Böden der Gydan-Halbinsel untersucht, mit dem Ziel, Zusammenhänge zwischen Bodenmorphologie und mittels elektrischer Tiefensondierung (Vertical Electrical Sounding, VERS) gewonnener Daten aufzuzeigen.
Die Ergebnisse zeigen, dass sich die untersuchten Böden hinsichtlich der Morphologie, Stratigraphie und Mächtigkeit des Auftauhorizontes wesentlich unterscheiden. Die Bodenhaupttypen der Gydan-Halbinsel (Sibirien, Russsische Föderation) sind Kryosole, die durch die Akkumulierung von schwach zersetzter organischer Substanz und Vergleyung gekennzeichnet sind. Diese Böden dominieren auf den Wasserscheiden und in den Senken, was mit schlechter Dränage bodenbildender Gesteine und dem Vorhandensein eines durchgehenden Frostbodens in der Landschaft verbunden ist. In einigen Fällen entwickeln sich zwei Gleyhorizonte in einem Profil: Ein erster im oberen oder unteren Bereich was auf saisonale Staunässe des Feinbodens zurückzuführen ist, und ein zweiter in der Kontaktzone zwischen Boden und Permafrost. Für die Senken sind Torfböden mit Kryogenesemerkmalen charakteristisch. Auf der Insel Beliy sind Böden verbreitet, die eine schwache Podsolierung im oberen Bereich des Profils aufweisen, was mit lithologischen Veränderungen in zunehmender Tiefe (Sand wird zunehmend durch Lehm ersetzt) verbunden ist. Der elektrische Widerstand (ER) wurde unmittelbar in den Bodenprofilen mittels der Methode der vertikalen elektrischen Sondierung gemessen. Dies ermöglichte die Daten über die Veränderung des elektrischen Widerstands unmittelbar im Profil ohne Bohrungen oder zusätzlichen Grabens zu bekommen. Diese Methode erlaubt es die Bodenheterogenität zu differenzieren. Die Methode der vertikalen elektrischen Sondierung wurde für die Untersuchung für Tiefen bis zu 500 cm eingesetzt; die Entfernung zwischen den Elektroden variierte von 5 bis zu 500 cm. Es konnte nachgewiesen werden, dass die Methoden der vertikalen elektrischen Profilsondierung für die Identifizierung des Frostbodens ohne Bohrungen oder des Anlegens von Bodenprofilen nützlich sind. Mit dieser Methode lassen sich Unterschiede im Bodenaufbau bewerten, da die Größe des elektrischen Widerstands von den Bodeneigenschaften abhängt und sich stark an den geochemischen Grenzflächen, einschließlich der Grenze von Auftauhorizont und des Permafrostboden, ändert.
Die Daten der vertikalen elektrischen Profilsondierung haben gezeigt, dass die obere Grenze des Frostbodens mit jener Grenze, die mit Hilfe der morphologischen Methode bestimmt wird, übereinstimmt. Die Methode ist ebenfalls für die Identifizierung der Gley-, Torf- und Podsolhorizonte anwendbar. Die Methode der vertikalen elektrischen Profilsondierung ist für die Bodenforschungen in den Regionen mit Permafrostböden nützlich. Sie ist außerdem für die detaillierte Aufnahme von Bodenschichten des Boden-Permafrost-Komplexes im Feld verwendbar.

INTRODUCTION

Soils underlain by permafrost are widely distributed in cold environments and prevail in soil cover structures of the Northern Hemisphere. Permafrost affects the soil genesis and morphology; it also regulates the main chemical and physical processes and determines the structure of the soil cover. Soils affected by permafrost are typical for Canada, Greenland, Scandinavia, Russia, China and Mongolia. Not all of them are Polar soils, because the Holocene permafrost is situated south of 60° N, mainly in Eastern Siberia and partially in Mongolia and China. The diversity of permafrost-affected soils is based on the cryopedogenesis process. The intensity of pedogenesis is controlled by the depth of the active layer, texture and structure of parent materials and the bedrock, and the climatic characteristics of the soil location. Permafrost is defined as the soil or bedrock layer with a temperature of about 0 °C or below for two or more consecutive years (Van Everdingen 2005). More than 60 % of the Russian land surface is underlain by permafrost (Kotlyakov & Khromova 2002), so soils with cryogenic features are very typical for the north, central and eastern parts of Russia. These soils are characterized by specificity in the sense of agricultural use or in the context of buildings or traffic communication constructions. Many of the permafrost-affected soils are considered to be Cryosols or Cryozems. The Russian soil classification scheme identifies "true" Cryozems (Vasilevskaja 1980) as soils, affected by permafrost and containing morphological features of cryoturbation. Other permafrost affected soils, which do not show cryoturbation morphological features are classified as soils of

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other classes or orders with an additional verifier "Cryic". The "Keys to soil taxonomy" (Soil Survey Staff 2010) have a class of Gelisols and WRB systems, which contain the Cryosol group (FAO 2014). The term "Gelisols" (soils with permafrost in the uppermost 1 m of the profile) is broader than the definition of a "Cryosol" (non-anthropogenic minerals soils with permafrost in the up-permost 1 m of the profile), whereas the term "Cryozem" is the most strictly defined in the sense of morphology. In any case, Cryosols and Cryozems, as parts of the Gelisols group are typical for the soil cover of Siberia, and those soils have shown intensive changes in morphology and thermal regime in the last few decades. Due to the climatic reasons there are changes of the active layer dynamics, namely an increase of its thickness, which affects the transformation of soil organic matter (Zubrisky et al. 2014), changes in soil cover spatial pattern (Desyatkin 2006) and soil evolution (Ivanov et al. 2015). Permafrost thawing due to the changing climate has been considered as one of the most important processes of evolution in the Polar environment in the North of Russia (Kaverin et al. 2014).

Active layer thickness and the depth of the permafrost layer are the basic features of soil cover of the Polar region and can be assessed by different direct or indirect methods. The classic method is to dig the soil profile or to drill the soil mass with the aim of fixing the border of the active layer and permafrost morphologically. It is also possible to push a sharpened steel bar into the ground until the frozen ground is encountered. This method has essential disadvantages – changing of local soil stratification and penetration of air and water from the upper solum to the bottom one. Nowadays, direct current resistivity (DC resistivity) methods have been used for the identification of permafrost depth and soil profile heterogeneity. Geophysical methods have many advantages (Scot et al. 1990) and have been widely used for permafrost identification (Hauck et al. 2003). This is a quantitative method, which allows to carry out quick measurements of ER along the different soil profiles and the permafrost layer. One of the main advantages of these methods is that the equipment is portable and easy to handle. The second one is the ability to detect the permafrost depth without drilling or soil-pit preparation. A one-dimensional model can be assumed for mapping of the permafrost depth in relatively homogenous conditions, whereas the two-dimensional approach was proposed for plots with a high degree of inhomogeneity (Hauck 2003, Pozdnyakov 2008).

Electric conductivity and resistivity depend on soil chemical composition, especially salt content, texture of the fine earth and soil moisture content (Pozdnyakov 2008, Magnin et al. 2015). It was substantiated previously (Pozdnyakov 2008) that vertical electrical resistivity sounding (VERS) method is useful for identification of the separate soil horizons. The method of VERS allows us to identify contrast between soil horizons and layer changes in vertical scale and provides the precise information about solum-parent material organization. On the basis of the published data (Pozdnyakov et al. 2008, Hauck et al. 2003, Gibas et al. 2005, Smernikov et al. 2008, Vanhala et al. 2009, Lastochkin 2013, Turu i Michels & Ros Visus 2013) we suppose that there are essential changes in values of electrical resistivity on the transition from the solum to the permafrost. Moreover, it has been previously shown that values of real electric resistivity (ER) are different for clays, sands, over-moistend layers and permafrost. ER can be only about 10-30 Ωm in clay-textured substrats, about 500 Ωm in dry sand or even up to 40000-80000 Ωm in permafrost layers. Measurements of ER and visualization are well known methods for permafrost mapping and identification of soil-lithological heterogeneity in vertical scale (Pozdnyakov 2008, Marchenko 2007).

Therefore, this work was aimed:
- to measure ER in soils of the Gydan Peninsula,
- to identify the depth of permafrost and active layer thickness, and
- to identity the differences in permafrost layer in the different latitude regions of the Gydan Peninsula.

MATERIALS AND METHODS

Description of study sites

This study was concentrated on investigation of soils of the northern part of the Yamal region (Northwest Siberia, Russian Federation) in the parts of the Gydan Peninsula, where the complex "Yamal-Arctica-2013" expedition had investigation sites and field camps during September and October 2013. The soils of the Yamal region are not very well known. Few studies on soil morphology and geography (Vasilyevskaya 1980, Ivanov 2015) have shown that this region is quite diverse and is expressed by at least four soil zones (deserts, barrens, tundras and forested tundras). The soils of the Yamal and Gydan Peninsulas are represented mainly by Gleyic and Cryogenic soils with low levels of chemical and biological pollution (Tomashunas & Abakumov 2014, Vlasov et al. 2014). The soils of the Yamal region are represented mainly by Cryosols, Gleysols, Histosols and some Al-Fe humus soils (Podsols) in the case of sandy textured grounds, e.g. on Belyi Island (Tomashunas & Abakumov 2014). In 2012, for the first time the Government of the Yamal-Nenets region, in conjunction with the Arctic and Antarctic Research Institute of RosHydromet, performed the first comprehensive expedition for the examination of the Yamal Peninsula (Complex Expedition Arctic Yamal-2012). The second expedition was organized in 2013 (Complex Expedition Arctic Yamal-2013). The principal areas of investigation were situated mainly on the Gydan Peninsula (Fig. 1). Measurements of the ER were conducted at the first time for soils of the Yamal region during this expedition. The areas of investigation belong to different climatic and landscapes regions of the Gydan region.

Soil morphology and general characteristics

Two different soils were investigated on the Yavay Peninsula (72°21.642' N, 075°05.144' E); the typical landscape of which is shown in Figure 2. One is a Histic Gleysol (Fig. 2 centre), with raw organic matter accumulation at the contact of a Gleyic horizon with the permafrost at a depth of about 37 cm. Those soils are located in relief depressions, called "layda" (Fig. 2 right). The second soil type is typical of well-drained and relatively dry uplands and hills. Those soils are identified as Cryosols, with gleyification only on the contact of fine earth with the permafrost layer at a depth of about 80 cm (Fig 2 left).

Fig. 1: Location of investigated sites of the Gydan Peninsula. 1: Haranasale Cape; 2: Yavay Cape; 3: Mamont Cape; 4: Enisey Gulf; 5: Belyi Island north of Yamal.

Abb. 1: Untersuchungsgebiete auf der Gydan-Halbinsel. 1: Kap von Haranasale, 2: Kap von Yavay, 3: Kap von Mamont, 4: Enisey Bucht, 5: Insel Belyi nördlich Yamal.

Soils of the Mamont Cape (71°18.812' N, 077°33.245' E, Gydan Yuribey Gulf) are represented by Histic Gleysol (Fig. 3 left, with two gleyic horizons: upper and contact one) and Gleyic Cryosols (Fig. 3 centre, also with two Gleyic layers). The landscape here (Fig. 3 right) is less differentiated in terms of elevation and is more saturated than the Yavay sites. The depth of the visible permafrost table here is about 60 and 90 cm for the Histic Gleysol and Gleyic Cryosol, respectively.

Relief forms of the Haranasale Cape (71°25.402' N, 073°03.758' E) are very different and are represented by hills and lowlands with relative elevation changes of about 100 m. Soils here are represented by Cryic Gleysols (Fig. 4 left), Histic Gleysols (Fig. 4 right) on Holocene loamy textured sediments and even Entic Podsols (Fig. 4 centre) in the case of sandy textured parent materials of aeolian genesis (WBR 2014). The permafrost table depths here are 110, 60 and 140 cm, respectively.

The landscape at Enisey Gulf (71°25.402' N, 073°03.758' E) is flat (Fig. 5 right), there is no expressed relief differentiation. Therefore, the soils and environments here are very saturated and Histic Gleysols dominate everywhere (Fig. 5 left). The depth of permafrost in both sampling sites of the Enisey Gulf is about 40-45 cm.

The soils of Beliy Island (Fig. 6) are represented by Entic Podsols with weak features of podsolization in the upper part, underlain by material affected by cryoturbation in the middle of the soil profile, the lower part changes to a Gleyic horizon (60-170 cm) of intensive blue colour, and is underlain by permafrost at a depth of 200 cm.

Methods of ER measuring

The ER of the soil profiles can be estimated from the vertical electrical sounding (VERS) measurements, which provides data on the changes in the electrical resistivity throughout the profile from the soil surface without digging pits or drilling. This method allows dividing the soil layer vertically into genetic layers with different properties and characteristics (Pozdnyakov et al. 1996, Pozdnyakov 2008). Different soil layers have different ER values, that is why the sharp changes in ER values in soil profiles can be interpreted as results of transition of one horizon to another (Pozdnyakov 2008).

In our study, the resistivity measurements were performed using four-electrode (AB + MN) arrays of the AMNB configuration (Fig. 7) with use of the Schlumberger geometry (Marchenko 2007). A Landmapper ERM-03 instrument (Landviser, USA) was used for the VERS measurements in this study. Vertical electric soundings (VERS) using the Schlumberger configuration were carried out at nine locations on different parts of the Gydan peninsula and in one station, situated on Beliy Island. The apparent resistivity readings at every VERS point were automatically displayed on the digital readout screen and then written down on the field note-book with taking into account the geometry factor.

A VERS was used to study the upper 0- to 5-m thick layer in greater detail. The distance between the A and B electrodes ranged from 10 to 1000 cm while the distance between the M and N electrodes was constant -10 cm. Electrodes were situated on the soil surface with depth of penetration into soil about 0.5 cm. The distance between MN electrodes were constant, while the distance between A and B electrodes were changes from 10 to 1000 cm. The soils were "sounded" thoroughly and found to vary between 5 cm and 3-5 m in A-B distances. A 1D layer model (ZonDIP program) of apparent and real resistivity's processing and visualization were used. This model provides the data on apparent resistivity values changes with the depth (ϱ), the layers thickness (h) and layer depth (z). Totally nine soil profiles from the different parts of Gydan Peninsula and one profile from Beliy Island were investigated. Field data presented by three replications of measurements at each point. The geometric factor, K, was first calculated for all the electrode spacings using the formula: $K = \pi\,(L2/2b - b/2)$, for Schlumberger array with MN = 2b and 1/2AB = L. The values obtained, were then multiplied with the resistance values to obtain the apparent resistivity, ϱa, values. Then the apparent resistivity, ϱa, values were plotted against the electrode spacing's (1/2AB) on a log-log scale to obtain the VERS sounding curves using an appropriate computer software ZONDIP.

The modeling of the VERS measurements carried out at fifteen stations was used to derive the geoelectric sections for the various profiles. These have revealed that there are mostly two or three geologic layers beneath each VERS station. Three resistivity sounding curve types were obtained from the studied area and these are the 1 ($\varrho1>\varrho2<\varrho3$), 2 ($\varrho1<\varrho2<\varrho3$) and 3 ($\varrho1>\varrho2<\varrho3>\varrho4$) type curves. Figures 7 and 8 show data and interpretation for the sites investigated. Measured apparent resistivity values (black dots) are plotted against half electrode distance and fitted by manual curve resulting from inversion process. Solid black line denotes the layer model and the thin

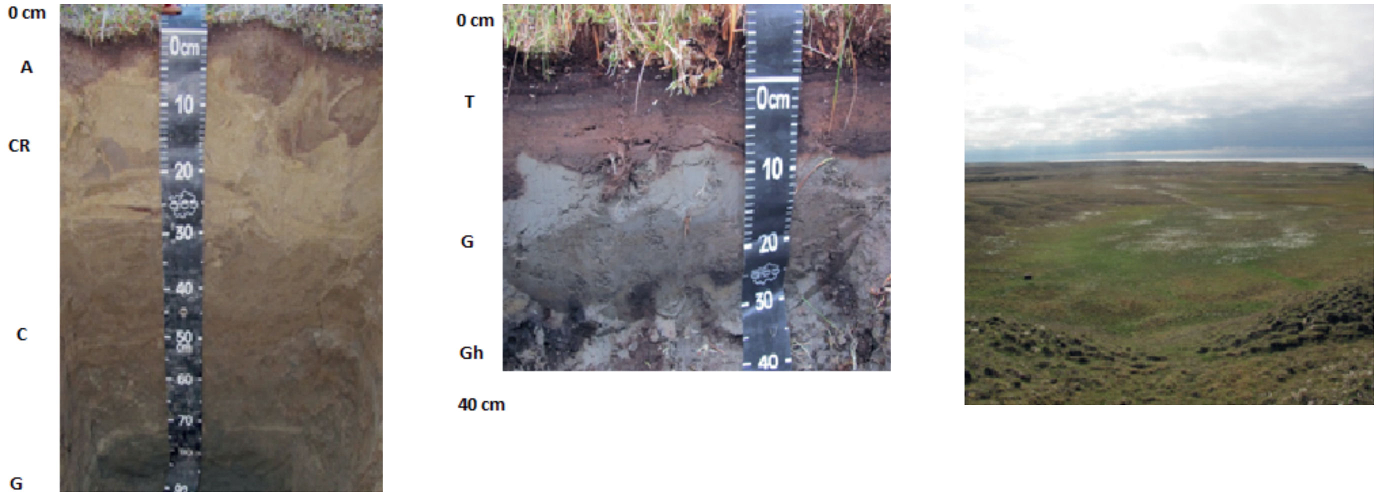

Fig. 2: Landscape at Cape Yavay (right; for location see No. 2 in Fig.1) and selected soil profiles showing soil horizons according to Russian soil classification. Left: a Cryosol; centre: a Histic Gleysol.

Abb. 2: Landschaft bei Kap Yavay, Gydan Halbinsel (rechts; siehe Nr. 2 in Abb. 1) und untersuchte Bodenprofile; Cryosol (links); Histic Gleysol (mittig).

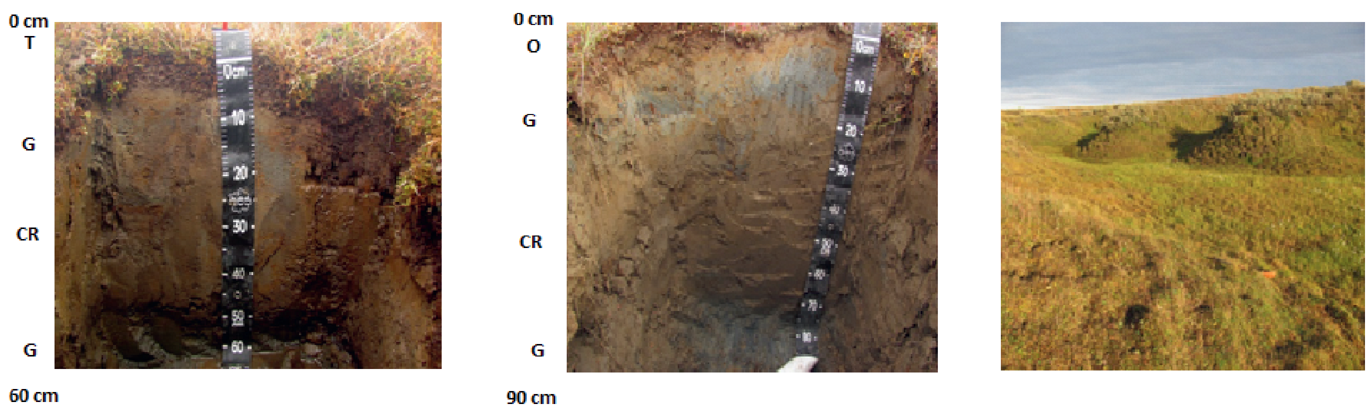

Fig. 3: Landscape with small valleys at Cape Mamont, Gydan Peninsula (right; for location see No. 3 in Fig. 1) and selected investigated soil profiles showing soil horizons according to Russian soil classification. Left: a Histic Gleysol; centre: a Gleyic Cryosol.

Abb. 3: Landschaft mit kleinen Tälchen bei Kap Mamont (rechts; siehe Nr. 3 in Abb. 1) und untersuchte Bodenprofile; Histic Gleysol (links); Gleyic Cryosol (mittig).

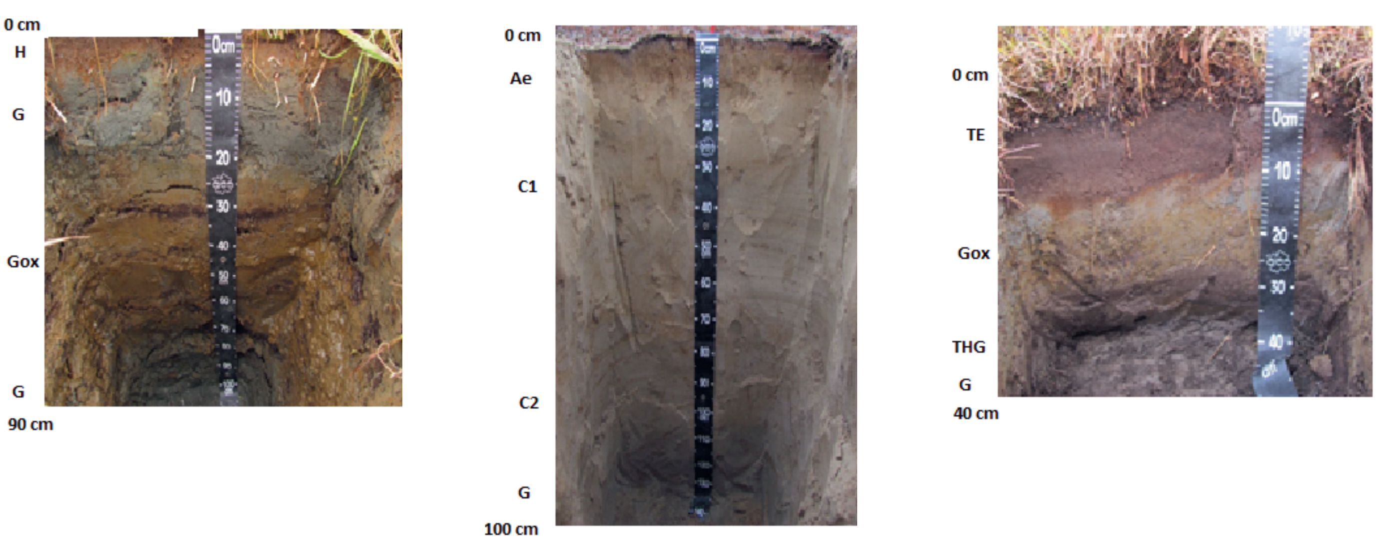

Fig. 4: Selected soil profiles investigated at Cape Haranasale (for location see No. 1 in Fig.1) showing Cryic Gleysols (left), Entic Podsol (centre) and a Histic Gleysol (right). Noted soil horizons according to Russian soil classification.

Abb. 4: Untersuchte Bodenprofile bei Kap Haranasale, Gydan Halbinsel (siehe Nr. 1 in Abb. 1); Cryic Gleysol (links), Entic Podsol (mittig) und Histic Gleysol (rechts) nach russischer Klassifizierung.

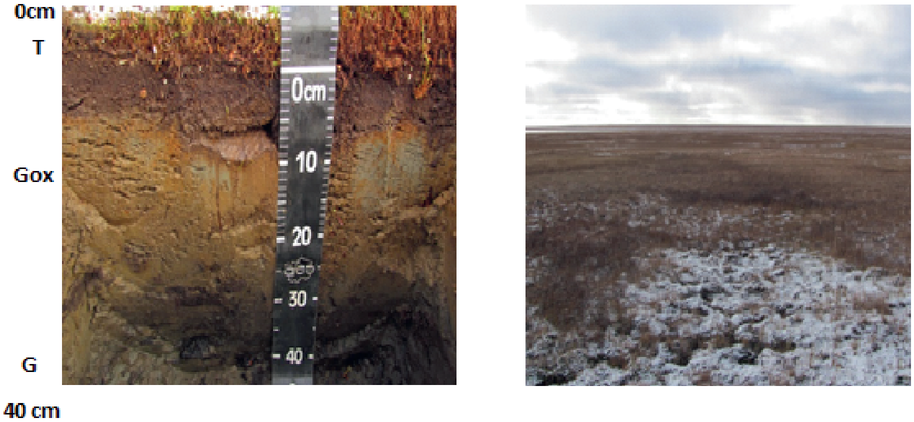

Fig. 5: Landscape at Enisey Gulf (right) and investigated Entic Podsol profile (left).

Abb. 5: Landschaft an der Enisey Bucht und untersuchtes Entic Podsol-Profil (links).

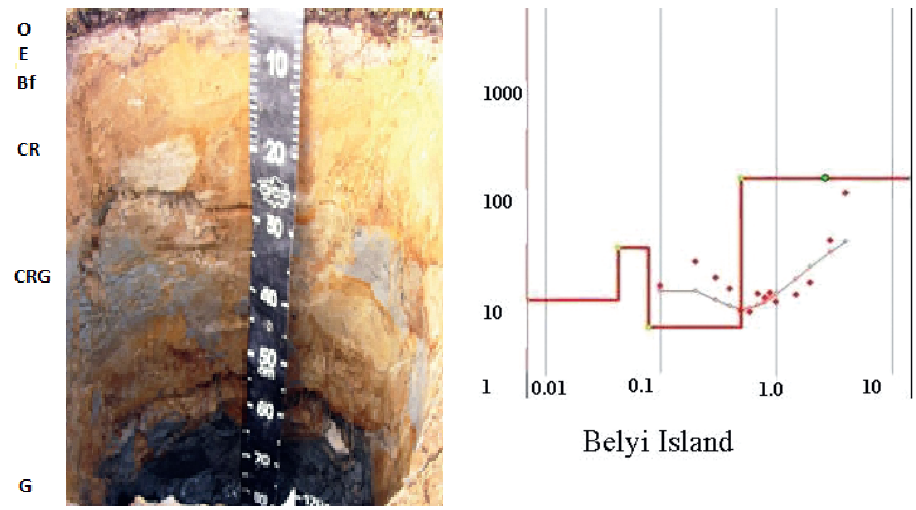

Fig. 6: Soil profile at Beliy Island (left; for location see No. 5 in Fig.1) showing Cryic Gleysol with Entic Podsol; right: Electric resistivity curve and model of soil profile (for explanation see Fig. 8).

Abb. 6: Untersuchtes Bodenprofil (links) mit Cryic Gleysol und Entic Podsol auf der Insel Beliy (Lokation siehe Nr. 5 in Abb. 1). Rechts: Kurve des elektrischen Widerstand und der Verlauf des modellierten Bodenmodels (vgl. Fig. 8).

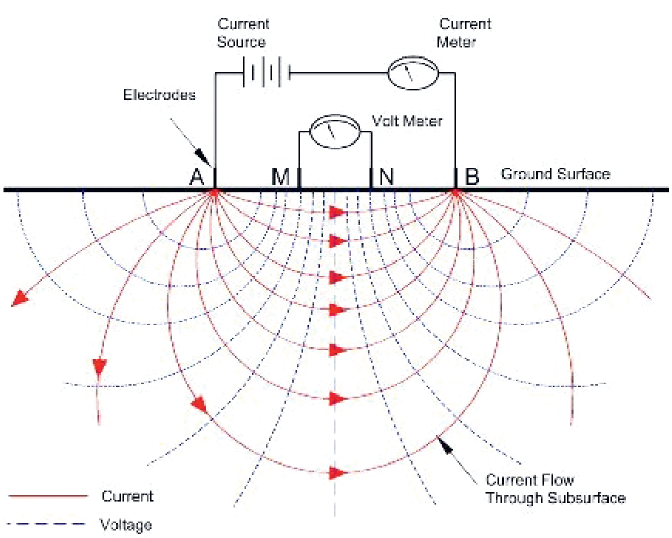

Fig. 7: Sketch of AB-MN electrode configuration.

Abb. 7: Skizze der Konfiguration der AB-MN Elektrode.

lines show the calculated model apparent resistivity curve. The purpose of the program ZONDIP is to determine the resistivity of the rectangular blocks that will produce an apparent resistivity pseudo-section that agrees with the actual measurements. The depths of the layers can also be changed manually by the user. The optimization method basically tries to reduce the difference between the calculated and measured apparent resistivity values by adjusting the resistivity of the model blocks. However it must be stated that small-scale lateral inhomogeneities will prevent very good agreement between model and observed data. This can be seen (Fig. 8) where only very general agreement between the shape of the model curve and observed data can be observed.

RESULTS AND DISCUSSION

Results of soil VERS measurement (Tab. 1, Fig. 8) essentially show heterogeneity of ER values within the soil profile. In general, there are notable sharp changes in ER values with soil depth, particularly in those layers, where the solum (active soil layer) is in contact with the permafrost table. The data obtained show that the upper border of the permafrost layer coincides with that ER transition, which was identified in field on the base of soil profile morphology. There is general trend of increasing ER in all the soils investigated in the line from the upper permafrost border to the lower limit of VERS measurement. It can be interpreted by invoking increasing permafrost homogeneity with greater depth. Namely, the number of cracks is lesser in the deepest horizons, and this is the reason why the amount of water, dissolved organic matter and iron oxides, penetrating into the deeper layers are lower here than on the geochemical border of the gleyic/permafrost contact.

Depth (cm)	Yavay Cape 1	Yavay Cape 2	Mamont Cape1	Mamont Cape 2	Haranasale Cape 1	Haranasale Cape 2	Haranasale Cape 3	Enisey Gulf 1	Enisey Gulf 2	Belyi Island
10	88	88	33	29	24	125	7	516	73	73
20	41	41	41	58	27	52	19	2635	183	123
30	814	814	22	82	44	42	27	5904	209	87
40	**856**	856	10	89	10	**155**	37	**10517**	287	67
50	2107	5389	31	86	6	232	48	15859	**490**	40
60	124	48969	112	**124**	2	245	60	22391	483	39
70	3246	93262	322	168	66	256	78	30364	750	**597**
80	3444	**915222**	220	200	45	289	92	40268	801	547
90	4363	89111	**457**	279	**103**	322	79	48952	989	619
100	5389	91552	376	282	81	325	**103**	54611	1410	495
150	12142	112224	1624	635	205	455	**173**	116056	4800	579
200	48969	125302	1130	1256	825	522	299	202531	1883	**778**
300	93262	180622	4804	3109	1224	499	512	461222	3674	2012
400	120596	221000	8542	4020	1658	526	724	819045	6532	5959
500	4860	260000	9062	4711	2748	687	942	96122	7852	6010

Tab. 1: Electric resistivity (Ωm) at the various sites of investigation (for locations see Fig. 1); bold: ER transitional zones.

Tab. 1: Elektrischer Widerstand (Ω m) an den verschiedenen untersuchten Standorten (vgl. Abb. 1); Übergangszonen fett markiert.

VERS section name	P-modelled resistivity (Ω m)	Z-bottom layer depth (m)	Field permafrost table (m)
Yavay Cape 1	123.3 8.9 6804.3	0.00 0.07 0.80	– 0.80
Yavay Cape 2	123.3 29.4 6528.3	0.00 0.04 0.40	0.37
Mamont Cape 1	68.3 14772.2 6169.2	0.00 0.60 1.10	– 0.60
Mamont Cape 2	46.5 7.1 11959.1	0.00 0.06 0.80	– – 0.90
Haranasale Cape 1	17.4 61.2 1.7 3847.3	0.00 0.05 0.10 0.50	– – – 0.50
Haranasale Cape 2	5.2 128.9 56.1 1319.1	0.00 0.08 0.30 0.90	– – – 0.80
Haranasale Cape 3	344.3 1712.2 108.7 10992.4	0.00 0.05 0.20 0.60	– – – 0.60
Enisey gulf 1	52.1 6720.6 1280. 7	0.00 0.10 0.50	– – 0.50
Enisey gulf 2	36.9 11466.3	0.00 0.40	– 0.40
Belyi Island	51.6 172.6 28.1 834.3	0.00 0.04 0.20 2.1	– – – 2.0

Tab. 2: Electric resistivity (Ωm).

Tab. 2: Modellierter Elektrischer Widerstand (Ω m) und daraus abgeleitete Horizontierung (m) im Vergleich zur direkten Feldmessung (m).

Soils of Yavay Cape (Fig. 8a, b) show very low resistance of the upper solum and ER values increases with depth. In the Cryosol there is increasing of ER values down to the 90-100 cm depth, which coincides well with soil morphology. In Histic Gleysol there is essential increasing of resistivity at a depth of 40 cm. Soils of the Mamont Cape (Fig. 8c, d) show different trends of ER value changes down the profile. Cryic Gleysols show low ER values due to clay texture in upper solum (Pozdnyakov 2008, Marchenko 2007), while the Histic Gleysol show the ER values higher in upper layer due to accumulation of raw humus material, than the values decreases in clay textured horizon and again increases in lower part of profile due to the permafrost table appearing.

Soils of Haranasale Cape show two trends of ER values distribution within the profile. Cryic and Histic Gleysols (Fig. 8e & Fig. 8g) show a rapid increase of resistivity with depth and crucial changes on the depth of 40-60 cm, where the permafrost layer appears. In Entic Podsol (Fig. 8f), there is a significant change of ER at a depth of about 80-90 cm, which good coincides with the field data of solum-permafrost stratification.

Soils of Enisey Gulf (Fig. 8h, i) show rapid changes in ER values within the depth and essential increasing of ER on the depth about 40-50 cm. At this depth the permafrost layer appears as it was described during the field investigations.

In case of the complicated soil profile at Beliy Island there is initially a maximum of ER (Fig. 6 right) in the podsolized sandy textured part (usually sand shows the higher ER values than loams or clays), while in the cryogenic loamy textured part are decrease of ER can be observed. Below ER values increase due to the permafrost table effect (200 cm).

Thus, the VERS provides precise data about the degree of soil-permafrost layer homogeneity/heterogeneity, namely,

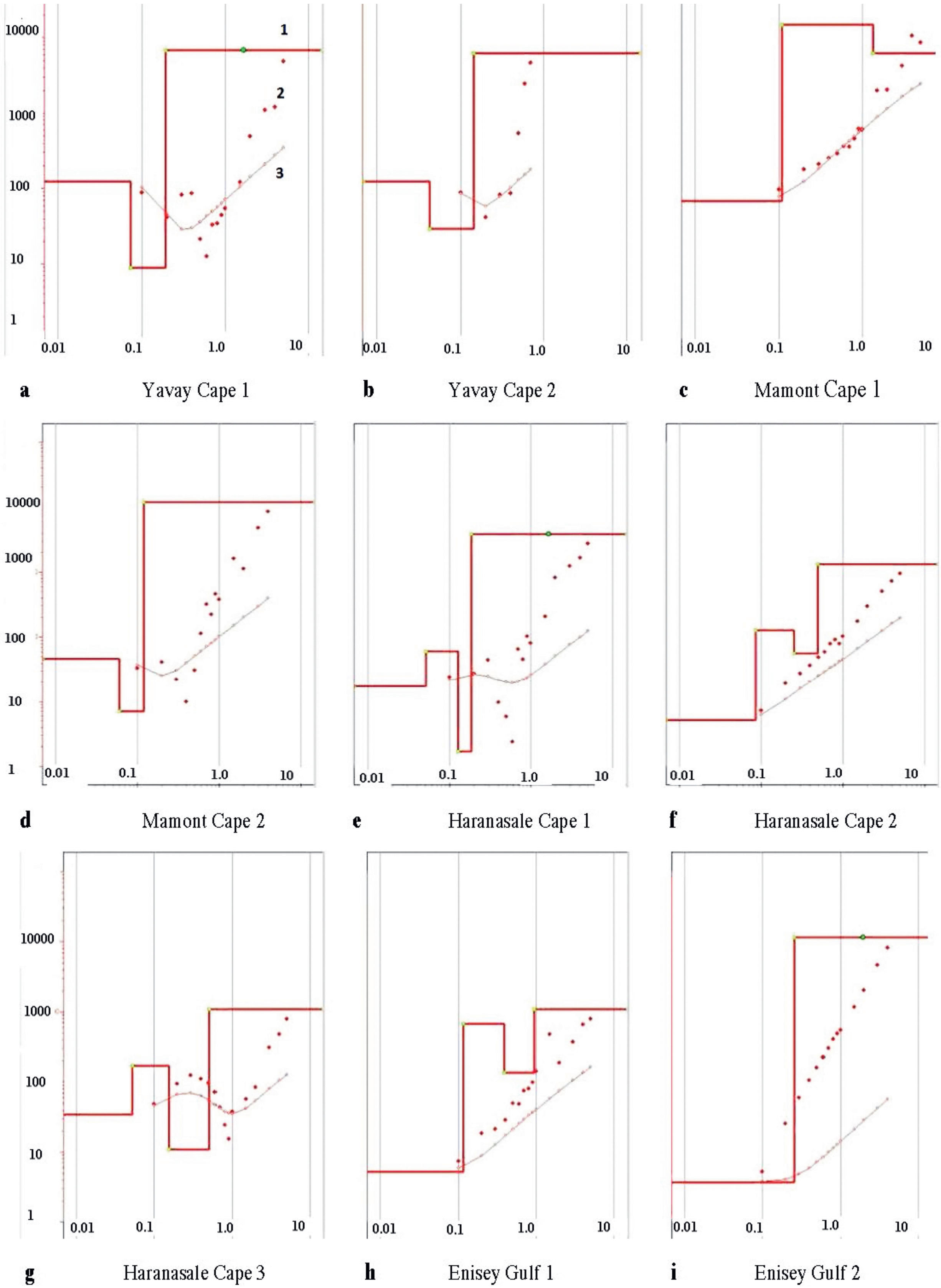

Fig. 8: Electric resistivity curves and models of soil profiles at investigated sites (for soil profiles see figures 2 through 6). Solid red line (1): denotes the layer model; dotted line (2): denotes measured values; thin lines (3): denotes calculated model curves. Vertical scale: ER values (Ωm); horizontal scale: AB/2 distance (m).

Abb. 8: Profile der Elektrischen Widerstandsmessungen und daraus modellierte Bodenprofile (Ansicht der Bodenprofile siehe Abb. 2 bis 6). Rote Linie (1) beschreibt das Model; rote Punkte (2) beschreiben Messwerte; dünne Linie (3) beschreibt die gerechnete Modellkurve. Vertikale Skala: ER-Werte (Ω m); horizontale Skala: AB/2 (m).

about soil stratification and presence of the geochemical barriers. The VERS method can be effectively used for identification of the active layer depth, for specification of soil-horizons and borders in field conditions and for the non-destructive mapping of soil cover.

CONCLUSIONS

Soils of the Gydan Peninsula are quite different in terms of solum morphology, soil stratigraphy and active layer thickness. The main soil types represented here are Cryosols with features of raw organic matter accumulation and gleyification features. These soils dominate on the watersheds and in low-lands due to poor drainage of parent materials and the presence of continual permafrost in the landscape. In some cases, two Gleyic layers form in one soil profile – one in the upper or middle part due to seasonal fine earth saturation, and second one on the contact of the solum with the permafrost. Histic soils with Cryic features are more typical for lowlands (relief depressions). Soils of Beliy Island are represented by slightly podsolized soils in the upper part; this is due to the lithological contrast of sediments (a sandy textured solum changes to a loamy textured one).

It was shown that the use of VERS methodology in the soil survey is useful for identification of the permafrost depth without digging of soil pit. This method allows the identification of soil heterogeneity, because the ER values are strongly affected by soil properties and intensively changes on the border of different geochemical regimes, i.e. on the border of the active layer and the permafrost. The lower changes were founded in cases where the Histic horizon changes to a mineral one and where the Podsolized uppermost sandy layer changes to a loamy textured one.

It can be summarized that VERS methodology is useful for preliminary soil surveys in the regions with permafrost-affected soil cover. It can also be applied for the elucidation of soil-permafrost layer stratification in field soil pits.

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